

# Incident Detection on an Arterial Roadway

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Presented here is the development of an automatic incident detection algorithm for use on Lakeshore Boulevard, Toronto, Canada, based on volume or occupancy data recorded from fixed-loop detectors. Four prospective logics were based on 20-sec intervals; the remaining five were based on traffic-signal cycle lengths to eliminate the fluctuations in 20-sec data. To identify the detection ability of each logic, data from a known severe incident (a two-lane blockage) were used. Only one logic exhibited promising results from the initial development and feasibility test: the logic that compared current cycle volume and occupancy values with those averaged over the previous 3-, 5-, and 10-cycle periods. Further evaluation was conducted on this logic. A data base was developed around two additional reported serious incidents; the logic detected both incidents before their official start times. A second data base, which consisted of data from 13 days, was developed to test the overall performance of this logic, focusing specifically on false alarms. On average, one unexplainable false alarm was reported for every 5 hr of data tested for the entire Lakeshore system (49 detector stations). Testing with additional Lakeshore incident data in a real-time environment is required to fully investigate the ability of this algorithm to detect serious incidents. As developed, this logic cannot distinguish between congestion due to incidents and recurrent congestion. The latter was responsible for the majority of the alarms as tested and thus future improvements should focus on this aspect.

As urban and suburban development continues to increase, the resulting travel demand will place an increased strain on already congested traffic networks. It is no longer feasible to build new roads or to increase the capacity of existing roads in an attempt to significantly improve the situation. The focus for remedial action therefore has changed from increasing the size of the network to improving its overall efficiency. One of the ways this has been accomplished is through the introduction of incident management systems. Incident management includes detecting and verifying the incident, responding with emergency vehicles and information for other motorists, clearing the incident, and monitoring traffic movements until normal operating conditions return (1). Such systems are developed not to eliminate congestion totally but rather to reduce the effects that traffic incidents have on road capacity and travel conditions.

Automatic incident detection (AID) on freeways has existed since the early 1970s, yet few applications have been developed successfully for arterial roadways because of the added complications that they possess. Han and May (2,p.7) identify the differences between freeways and arterials that are responsible for the lack of research:

Freeways have limited access points and reduced median and marginal friction. Freeways generally have less geometric constraints and a more homogeneous vehicle mix than surface streets. Traffic speed and flow is typically more uniform on freeways than on arterials. In addition, arterial detectors generate a great deal of noise. And finally, a high degree of uncertainty is associated with operational problem detection on surface streets.

Unlike on freeways, where the presence of a stationary vehicle might suggest an incident, identifying an incident on signalized urban arterials is much more complex (3). Normal behavior patterns of arterial motorists often include routine stops—at traffic signals, waiting to complete a turning movement, or momentarily parking—all of which would not be expected of freeway travelers. As the number of travelers on urban arterials increases, exceeding 100,000 vehicles per day in some instances (4), the need for AID becomes more important. Although implemented more for traffic management reasons than for safety reasons (5), the goal continues to be the identification of capacity-reducing incidents.

This paper describes the results of an evaluation of nine methods for identifying incidents on arterial roadways. The first section reviews previous efforts to develop arterial incident detection techniques and draws some guidance from these. The second section describes the location for the test, which was Lakeshore Boulevard in Toronto. The third section covers the initial feasibility testing of the nine logics used. The best of these is given further testing in the fourth section. The final section of the paper offers both conclusions and cautions about the methods and the task.

## PREVIOUS EFFORTS TO DEVELOP ARTERIAL INCIDENT DETECTION

Traffic incidents are not limited to vehicular collisions, but also include stalled vehicles, illegal parking, debris on the roadway, and others. An encompassing definition of an incident is that of the Commission of the European Communities Cooperation in the Field of Scientific and Technical Research (EUCO-COST 30, 1979) as cited by Thanacanmootoo and Bell (6,p.1): “An event which causes a need for assistance of involved drivers and/or warning of oncoming traffic in order to maintain safe driving conditions.”

Common to most incidents is their effect on existing travel patterns. Often an incident is followed by a sudden, temporary decrease in road capacity, which results in traffic queues, reduced speeds, and increased travel times, and potentially results in additional secondary incidents. It is important to note that an AID system using traditional traffic data can detect only the symptoms of an incident (e.g., decreased volume and increased occupancy upstream; decreased volume and decreased occupancy downstream) and cannot detect the incident itself (7). On an arterial roadway, therefore, an incident must be severe enough (e.g., a multiple-lane blockage that occurs during moderate to heavy flows) for the effects to be differentiated from normal operating conditions.

Most AID algorithms can be classified on the basis of their fundamental approach to processing traffic data. Pattern-recognition algorithms compare existing traffic patterns, determined from measurements of volume and occupancy, with historic data. Examples include those developed for use with the Smart Corridor Demonstration Project in Los Angeles, California (2,8,9), and for use with the ADVANCE project in Chicago, Illinois (7,10–15). Differences

between the current and historic values that exceed predetermined thresholds indicate the presence of an incident. The downfall of pattern recognition is that for the best results, the thresholds must be calibrated independently for each station. This can be somewhat tedious for AID systems that incorporate a large number of detector stations. In addition, these thresholds may be dependent on the time of day and the day of the week (7).

Short-term prediction algorithms utilize various statistical procedures with previously recorded data to predict future traffic measurements. An incident is declared when the deviation between observed and predicted measures exceeds a predefined threshold. The advantage to short-term prediction algorithms is that the calibration procedure is operating continuously and the thresholds are updated continuously. Therefore, the data most recently measured are used to establish the range of acceptable nonincident values for the next measurement (7). An initial algorithm development by Bell and Thancanamootoo (5) and Thancanamootoo and Bell (6) has since been further improved by Bretherton and Bowen (16).

Three lessons can be gained from a review of these previous efforts. The first two relate to the level of aggregation of the data. Temporally, because of the cyclic nature of traffic at signal-controlled junctions, each algorithm utilized traffic counts aggregated over longer intervals than the shortest available (e.g., 20 sec). Included were periods of 1 min (8), one cycle length (2,5,9), and three cycle lengths (10). Each verified that although the data were aggregated and thus smoothed, incident patterns remained evident. For this new study, data will be aggregated to cycle lengths. Spatially, most of the previous efforts used data aggregated or averaged across all the lanes of the facility. Based on insights from development of the McMaster freeway incident detection algorithm, this new study will use lane-specific data.

The third lesson is that the majority of the algorithms initially have been developed and verified using simulated data. This raises the issue of how valid such data are and whether similar results can be accomplished through the use of real data. Bell and Thancanamootoo (5) used a very limited amount of field data from SCOOT detectors, which "measure traffic demand in hybrid units of flow and detector occupancy" (17,p.2) rather than in conventional units. Only the logic of Han and May (2), further developed and implemented in the Smart Corridor Project, has utilized an extensive quantity of field data (8). After 3 months of on-line operation, the AID system "averaged approximately 100 identified potential incident locations on a typical day for the 788 detectorized link arterial network" (8,p.5). However, only "a small percentage" (8,p.5) of these were brought to the attention of the operator; the majority were cleared by the system itself without operator intervention. One advantage of the analysis in the present study is that it can draw on real data throughout, so the validity of the exercise will not be an issue.

## LAKESHORE BOULEVARD CORRIDOR AND DATA

Lakeshore Boulevard, located along the north shore of Lake Ontario in Toronto, Canada, was chosen for the development of an arterial incident detection algorithm because of its high daily traffic (12,000 to 20,000 vehicles per day). In addition, combined with the Gardiner Expressway (a freeway facility), it forms a vital traffic corridor into and out of downtown Toronto. Lakeshore Boulevard has three lanes in each direction, 22 signalized intersections (17 of which use SCOOT signal control), and 49 vehicle detector stations (separate from SCOOT detectors) over its 11.7-km length.

The existing Lakeshore Corridor Traffic Management System incorporates extensive remote video coverage, inductive-loop detector stations, and system operators to monitor traffic conditions 24 hr/day, 7 days/week (18). Incident detection is accomplished through visual inspection of the video coverage or as a follow-up procedure to secondary sources such as traffic and police reports. The goal in developing an automatic arterial incident detection algorithm is to provide a suitable replacement for manual detection, although system operators still will be required to verify the algorithm results and proceed with follow-up measures.

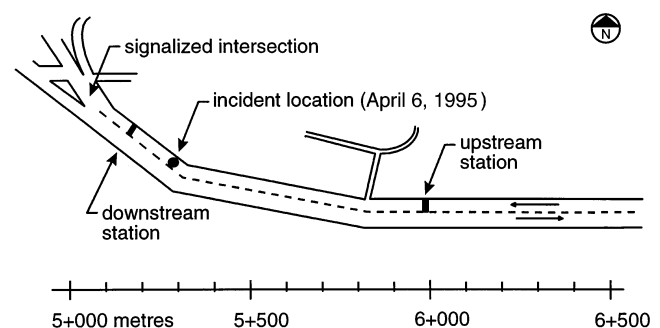
Traffic data measured by the loop detectors consist of 20-sec counts of both volume and occupancy measured 24 hr/day over each traveled lane. The procedure to measure and record the traffic data is similar to approaches used with freeway systems. However, the data values differ considerably from freeway measures because of the reduced speeds and volumes accommodated by the arterial roadway and because of the stop-and-go effect of the traffic signals.

Only data from 6:30 a.m. to 7:00 p.m., characterized by moderate to heavy volumes, were used. This period captures both the a.m. and p.m. peak hours, during which severe incidents would be most critical. AID systems are not expected to detect incidents that occur outside of this period because of their minimal effect on traffic. To reduce the inherent fluctuations in the 20-sec data due to nonincident conditions, data were aggregated over typical signal cycle lengths, depending on the time of day. Analysis of actual SCOOT signal data revealed that 100- and 120-sec cycle lengths were representative of the off-peak (9:30 a.m. to 3:30 p.m.) and peak (6:30 a.m. to 9:30 a.m. and 3:30 p.m. to 7:00 p.m.) hours, respectively.

## PRELIMINARY TESTING

The development and feasibility testing of the nine proposed AID logics initially focused on the detection of one known serious incident. Further testing (described in the next section) of the most successful logic involved data from a number of serious incidents and also data from incident-free days to allow complete investigation of detection rates, false alarm rates, and times to detection. The preliminary test results are grouped into two categories. In the first, the 20-sec volume and occupancy data are used directly. In the second, average volume and occupancy values are calculated once per cycle.

The incident chosen for the initial development occurred on April 6, 1995, on westbound Lakeshore Boulevard. Figure 1 illustrates the incident location with regard to the immediate upstream and downstream detector stations and depicts the nearby signalized



**FIGURE 1** Location of incident on Lakeshore Boulevard, April 6, 1995.

intersection. The operator's log indicated that at 16:17:31 an accident blocking the outside lane (Lane 3) was detected. At 16:24:13, the incident status was updated, at which point the center lane (Lane 2) also was declared blocked. The incident was officially declared over when all traveled lanes were cleared, at 16:35:23. In total, the duration of the incident was 17 min 52 sec (11 min 10 sec of two-lane blockage). Note that the end of the incident, as recorded in the operator's log, refers to the clearance of the accident rather than the return to operating conditions experienced before the accident. Figures 2 and 3 illustrate both the 20-sec and the average cycle volume and occupancy counts, from 4:00 p.m. to 5:00 p.m. for Lane 1 of the downstream detector station (the most affected lane at the closest station). The times corresponding to the beginning of the one-lane blockage (16:17:31), the beginning of the two-lane blockage (16:24:13), and the ending of the incident (16:35:23) are indicated by the bold vertical lines. Note that traffic conditions were not severely affected until the second lane was blocked. As such, an AID system is not expected to identify the incident before this time.

### Logics Updated Every 20 Sec

The first set of logics for the development of an AID algorithm updated the data every 20 sec despite the earlier findings that data aggregated over a single cycle length are capable of maintaining incident-related patterns. Twenty-second intervals were adopted in an attempt to declare incidents with a minimum time to detection. On average, the minimum time to detection should be between 0 and 40 sec (i.e., the incident occurs in one 20-sec interval and is detected at the end of the next 20-sec interval). Each 20-sec logic will be discussed briefly as will its ability to detect the known incident on April 6, 1995. Four logics are discussed, two in the first subsection.

#### Volume or Occupancy with Standard Deviation

Adapted from an earlier freeway incident detection algorithm (19), this logic determined average cycle volume or occupancy (updated every 20 sec) and compared each with limiting bounds (average of

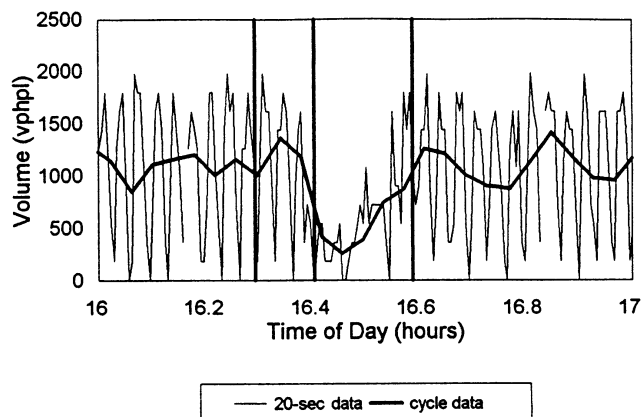


FIGURE 2 Downstream incident station, Lane 1, April 6, 1995: 20-sec and cycle volume counts.

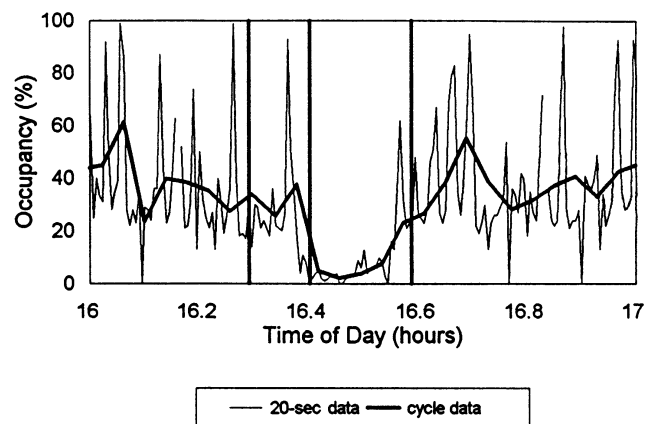


FIGURE 3 Downstream incident station, Lane 1, April 6, 1995: 20-sec and cycle occupancy counts.

three previous cycles plus or minus two standard deviations). An incident alarm was declared each time the one-cycle mean value violated the lower bound for the volume analysis or violated either the upper or lower bound for occupancy. The principle behind this is that a sudden change in traffic data would have a substantial effect on the one-cycle average while having less of an effect on the three-cycle average and corresponding standard deviations.

At the upstream station, volume and occupancy each resulted in one true incident alarm accompanied by 92 and 238 false alarms, respectively. The incident was not detected at the downstream station, where 101 and 107 false alarms were reported for volume and occupancy. This logic was not investigated further.

#### Occupancy Standard Normal Deviate

Dudek et al. (20) proposed a standard normal deviate (SND) model that investigated the rate of change of freeway occupancy. Incidents would be declared when the SND value determined by the model exceeded a given threshold.

Analysis using variations of the model for arterial applications was completed using one- and three-cycle average occupancy values, both updated every 20 sec, to determine which was more responsive to changes in arterial traffic. Neither the one- nor the three-cycle SND value exceeded any particular positive threshold at the time of the incident. In general, although distinct patterns existed during the incident period, reliable detection was made difficult by the repeated fluctuations in both the one- and three-cycle SND values. Therefore, this method of incident detection was rejected.

#### Volume and Occupancy with Lower Bound of Uncongested Data

The McMaster Freeway Incident Detection Algorithm was developed around the concept that the prevailing traffic conditions can be defined by the location of the measured data in one of two regions on a volume-occupancy plot (21). The regions are defined by a lower

bound of uncongested data (LUD). Any data located to the right of this line (or below it) are within the congested realm, resulting from recurring traffic congestion or a traffic incident. Although the algorithm was developed with freeway data, the general principles associated with it can be transferred to a signalized arterial environment for testing.

Figure 4 illustrates time-connected volume-occupancy plots for Lane 1 of two stations affected by the incident. The heaviest line is the LUD. The bold lines define data measured during the time of the recorded incident. The downstream station is located approximately 120 m downstream of the incident and 160 m upstream of a signalized intersection. Its proximity to the traffic signal results in numerous data located to the right of the LUD line, indicative of vehicles slowing or stopping at the signal. The incident data are indistinguishable from the normal data at this location. This method apparently cannot be used at detector stations within the influence zone of traffic signals.

The upstream station is located approximately 700 m upstream of the incident and 980 m upstream of the signalized intersection. As can be seen from the plot, the number of congested data points is reduced substantially as compared with the downstream station. Many of these points correspond to the incident rather than to normal operating conditions, as the effects from the signalized intersection are lessened. However, the points that are not related to the incident still may result in false alarms. Several placements of the LUD were tested, along with different persistence checks (i.e., the number of congested data points required before an alarm is declared). The best result achieved was a minimum time to detection of 1 min 34 sec (after the second

lane became blocked) with three false alarms. Although the results are promising, other logics produced better results.

### Logics Updated Every Cycle

The second approach to developing AID logics investigated the use of 20-sec volume and occupancy measures aggregated and averaged at the end of the cycle lengths previously discussed. This approach results in smoother data trends, from which deviations as a result of traffic incidents are easier to detect, but it also results in a greater time to detection. Five logics and their abilities to detect the known incident will be discussed.

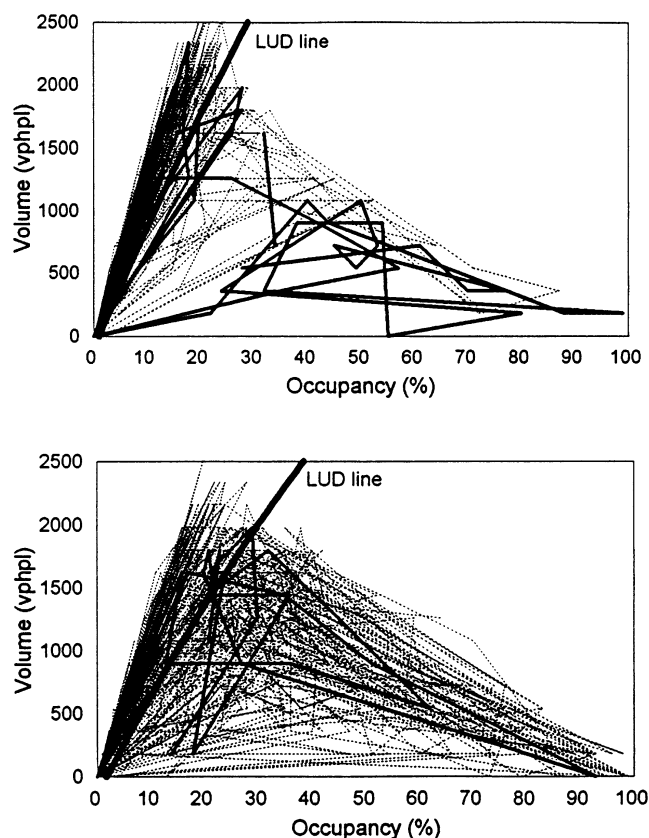
### Volume or Occupancy with Previous Cycle Measures

The first two logics developed for use with cycle data will be discussed together because they are similar for the two variables (volume and occupancy). These approaches compare the present cycle volume or occupancy with the average volume or occupancy over the previous 3, 5, and 10 cycles. Severe changes in traffic patterns will have a considerable impact on the values of the cycle in which they occur, whereas the impact on the previous 3-, 5-, and 10-cycle average values will be less. Incidents can be declared by a substantial decrease in the volume, or a substantial increase or decrease in occupancy, on any of the traveled lanes. Threshold values of 600 vehicles per hour per lane (vphpl) for volume and 20 percent for occupancy were determined from inspection of the raw incident data.

Incidents can be declared over when the opposite of what was used to detect the beginning of the incident occurs again in any of the lanes. However, if an incident is cleared slowly over a long period, traffic conditions may gradually return to normal with the result that no abrupt changes in the volume or occupancy will be observed. Therefore, the logic that uses occupancy alone will be unable to distinguish the end of an incident from its beginning on a reliable basis. If the end of one alarm is missed, the next similar change in occupancy may be misclassified as the end of the earlier incident. As a result, this logic will declare alarms at both the beginning and the end of each incident; end-of-incident alarms will be considered false alarms. More emphasis will be placed on the initial detection of the incidents rather than on their clearance.

Each logic was able to successfully identify the occurrence of the incident at both the upstream and downstream stations but resulted in an unacceptable number of false alarms. In addition, the treatment of end-of-incident alarms as false alarms makes the occupancy criterion unfavorable.

The third logic combines the approaches of the first two. For an alarm to be declared, both the volume and occupancy criteria must be met using data from the same lane and the same previous average. The end of an incident can be distinguished successfully from its beginning by using both volume and occupancy. If either the volume or occupancy data are invalid for a cycle because of missing or erroneous data, the logic will continue to operate on the basis of the remaining variable. Resulting alarms will be flagged for further investigation by system operators. If this approach is adopted, the results will be more conservative in that all potential incidents will be addressed, unless an incident has occurred and both the volume and occupancy data are invalid. The known incident was successfully identified at both the upstream and downstream stations with times to detection of 4 min 33 sec and 0 min 33 sec, respectively, with no additional false alarms. The 4-min



**FIGURE 4** LUD method time-connected plot for Lane 1 of the two incident stations, April 6, 1995: *top*, upstream station; *bottom*, downstream station.

differential is due to the distance between the detector station and the incident location (the upstream station is an additional 580 m from the incident). The end of the incident was declared at the upstream station 1 min 22 sec after the reported end time and 0 min 37 sec before the reported time at the downstream station. Recall that the detection logic operates on the basis of incident-related congestion, whereas the operators report on the presence of the incident. Thus slight discrepancies in times are to be expected.

#### *Occupancy SND*

This occupancy SND approach is analogous to that previously used except that the data are updated every cycle rather than every 20 sec. In addition, the sampling periods were based on 3-, 5-, and 10-cycle durations, resulting in three distinct SND values. Three values were investigated to capture incidents that occur suddenly and would thus affect the three-cycle value and those incidents that occur over a greater period. Incident alarms were declared when any of the three values exceeded a threshold of 10, estimated from the incident data and corresponding SND plots. Again, this logic cannot differentiate between the beginning and ending of incidents because of its reliance on occupancy alone. Therefore, each violation of the threshold resulted in an incident alarm.

The number of resulting false alarms far exceeded the number of potential true alarms when all three SND values were used (3-, 5-, and 10-cycle SND values). Because of the remaining fluctuations in the occupancy measure across 3 cycles (somewhat less across 5 and 10 cycles), the 3-cycle SND values resulted in the majority of the false alarms and hence were subsequently discarded. The analysis with only the 5- and 10-cycle values resulted in one false alarm at each station and one true alarm at the upstream station with an acceptable time to detection. However, because of the inability of the occupancy SND approach to detect the incident at the downstream station and its treatment of ending alarms as false alarms, further investigation into its use as a reliable detection tool ceased.

#### *Volume and Occupancy with LUD*

Again, this approach mirrors that discussed for 20-sec data except that average cycle values are used rather than 20-sec data. This reduces the number of data points and results in much cleaner volume-occupancy plots on which distinct uncongested and congested regions remain apparent.

At the station that is immediately upstream of the traffic signal (and downstream of the incident), a large number of cycle data points remain within the congested region despite the overall reduction in the number of points. Therefore, only the upstream station, which is located outside of the signal influence zone, was investigated with this logic. Several LUD lines were tested. The best result was a time to detection of 2 min 33 sec with no false alarms. Despite this, the alterations to this logic to accommodate cycle data did not yield improved findings; this logic still is dependent on signal and incident location and still requires station-specific calibration.

#### **Preliminary Conclusions**

The volume and occupancy data based on signal cycles, rather than 20-sec counts, provided an improved basis for algorithm develop-

ment because the fluctuations caused by the traffic signals were diminished. This substantiates the findings from earlier studies (2, 5, 6, 9). The approach that compared both volume and occupancy for the present cycle with their respective averages over the previous 3, 5, and 10 cycles was capable of detecting the incident at the affected stations with a minimal time to detection and no false alarms. In addition, given reliable data, this logic is capable of distinguishing between the beginning and ending of incidents; hence it is the only one that will be carried forward for further testing.

#### **OFF-LINE TESTING**

This section provides more extensive off-line testing of the most successful logic. It investigates the logic's ability to detect additional severe incidents and to operate during normal conditions without false alarms. Two data bases were created. The first consists of data only from known severe incidents; the second consists of data from a more extensive period, including incident and nonincident periods.

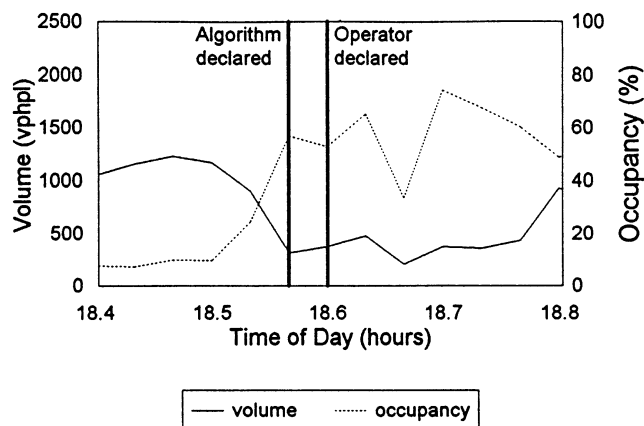
##### **Incident-Specific Data Base**

The incident-specific data base comprises data recorded on days during which incidents resulting in the blockage of two or more of the three traveled lanes were reported. Despite the high volume of daily traffic along Lakeshore Boulevard, the number of suitable incidents was only 14 for 1995 (not including the incident of April 6). Seven of these occurred outside of the hours of heavy traffic, 6:30 a.m. to 7:00 p.m. Of the remainder, only two were acceptable for use because of invalid data at the stations near the incident or because of incident patterns that did not differ substantially from normal operating conditions, or both. The reported durations of the two incidents are approximately 1 hr 47 min (18:35:51 to 20:23:08) and 6 min (14:41:37 to 14:47:11) for June 8 and July 17, respectively.

Only data from incident stations (i.e., those immediately affected by the incident) were investigated. Included were the data from the upstream and downstream stations for the incident of June 8 and the upstream station for the incident of July 17 because the downstream data were invalid. The logic detected the June 8 incident at the upstream station only, approximately 2 min before it was reported officially by the system operators, with four additional false alarms. The July 17 incident was detected approximately 20 min before it was reported. Figure 5 illustrates the volume and occupancy for Lane 2 (the lane in which alarms were declared) of the upstream station of the June 8 incident. The first vertical line represents the time at which the algorithm declared the alarm; the second corresponds to the operator's report. The early detection of both incidents by the algorithm suggests that such a system can be of value in an arterial traffic management system. Not only could it be less dependent on operators for incident detection, but any resulting earlier times to detection would help minimize the compounding effects of the incident.

##### **Extended (Nonspecific) Data Base**

The extended data base consists of 20-sec volume and occupancy data recorded at all of the detector stations along Lakeshore Boulevard (24 stations westbound and 25 eastbound) during the period 6:30 a.m. to 7:00 p.m. In total, 13 weekdays sampled from the period



**FIGURE 5** Lane 2 cycle volume and occupancy for upstream incident station, April 6, 1995.

February 2 to November 17 were represented. Although the main purpose of this testing is to investigate the number of alarms declared during nonincident periods (i.e., alarms declared by the logic but not supported by operators' incident logs), alarms resulting from true incidents also will be addressed. It is difficult to obtain data from all stations for such an extensive period without the occurrence of some type of incident. The data from July 17 were included in this data base to investigate the alarms that may occur at the stations not affected by the incident; the June 8 incident was not included because the data set was not complete for all detector stations.

A total of 94 incident alarms were declared during the 13 days tested. Seven resulted from the violation of both the volume and occupancy criteria; 7 were based solely on volume (invalid occupancy); and the remaining 80 were based on occupancy alone (invalid volume). Only 2 of the 94 alarms correspond to reported incidents—the multilane accident of July 17, previously tested (which was the only incident of its kind in this data base), and a stopped car blocking a single lane reported on October 30. The latter incident was detected by the algorithm 34 sec before it was officially reported. Although it has been said that the logic will work only with severe incidents, the algorithm is capable of detecting minor incidents (e.g., single-lane blockages) if their effect on traffic is substantial.

The operators' logs describe the occurrence of events other than accidents, such as the presence of maintenance crews and traffic congestion resulting in the development of queues, which can be used to explain additional alarms. They would not be considered false alarms per se because they can be accounted for and do represent an incident as defined earlier. Three of the alarms occurred during periods of maintenance reported in the vicinity of the station. All three of these alarms occurred in a lane that was not blocked by the maintenance crew, as expected. The recorded presence of traffic queues accounted for an additional 24 alarms.

Investigation of the operators' logs explained 27 of the 92 non-accident alarms, leaving 65 to be accounted for. Twelve alarms declared at one station can be attributed to recurrent congestion related to geometrics. An off-ramp from the overhead Gardiner Expressway enters Lakeshore Boulevard approximately 10 m downstream of the station, allowing freeway traffic to merge with the arterial traffic. An additional 19 alarms, all of which were declared in the afternoon or evening hours, occurred at one other station. The absence of alarms

in the a.m. peak period and the presence of 10 other alarms that were associated with reported traffic queues suggest that this station experiences recurrent congestion also. It is possible that the conditions that resulted in the 19 alarms at this station, although severe enough to warrant an alarm, did not warrant entry into the operators' logs.

Thirty-four alarms remain unaccounted for, which translates to approximately one unexplained alarm for every 5 hr of data tested over the entire system of 49 detector stations. They can be attributed to temporary disruptions in traffic conditions or perhaps to real incidents that the operators missed. Note that only 3 of these 34 alarms are based on violation of the volume and occupancy criteria together. If alarms are declared solely on the basis of the occupancy criterion, the same problems as those previously discussed must be considered; there is no distinction between alarms corresponding to the beginning of an incident or its end.

If it is desired that the logic detect only accidents, the logic would be limited to those that are severe and it would declare numerous false alarms resulting from nonaccident congestion. Alternatively, if an alarm is desired each time traffic conditions become congested, regardless of cause, the detection logic will work well. In this case, each alarm declared by the violation of the volume and occupancy criteria will be a true alarm, although not all will warrant further action by system operators.

## CONCLUSIONS

The goal of this paper is to develop an AID algorithm for use on Toronto's Lakeshore Boulevard, a signalized arterial roadway. An effective algorithm would have a high incident-detection rate, a low mean time to detection, and a minimal number of false alarms. Of the nine detection logics tested, only one was able to detect consistently the known severe incidents, regardless of their location with respect to traffic signals and loop detectors, with acceptable times to detection. This logic compared the present cycle volume and occupancy with the average volume and occupancy over the previous 3, 5, or 10 cycles to determine if substantial changes had occurred. An incident upstream of the detector station resulted in drops in both volume and occupancy, whereas an incident downstream of the station resulted in a drop in volume accompanied by an increase in occupancy. The extent of the changes in the measures is dependent on the severity of the incident.

Despite the success of this logic, shortcomings must be investigated further.

1. On-line testing should be completed to evaluate the effectiveness of this logic in a real-time environment. It is necessary to investigate the alarms as they occur so that the variations in traffic data that result in alarms can be determined.

2. The detection logic currently uses fixed volume and occupancy thresholds (600 vphpl and 20 percent). However, this will result in incidents being detected only during periods in which the violation of the thresholds is possible. To allow for periods of low flow and low occupancy, or low flow and high occupancy, the thresholds can be changed to a percentage basis rather than finite values. A related improvement might involve the use of threshold values that are dependent on the time of day to allow for different travel behaviors. Both the sensitivity and the number of such thresholds would have to be investigated.

3. Three time periods were investigated in this paper: 6:30 a.m. to 9:30 a.m., 9:30 a.m. to 3:30 p.m., and 3:30 p.m. to 7:00 p.m. A cycle

length for each was determined from actual measured cycle lengths along Lakeshore Boulevard. These periods can be segregated further to allow for more responsive cycle times.

These recommendations will improve the ability of the detection logic to work within an on-line incident management system and should result in higher detection rates, a lower number of false alarms, and lower times to detection. However, although these recommendations already have been identified, the proposed algorithm has been shown to be effective and can be implemented without additional improvements.

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